3.15 RESULTS FOR WAVEFORM GENERATOR

The purpose of the radar transmitter is to emit an RF signal having characteristics favorable for processing of similar signals reflected from a target. Transmitter performance in *RADGUNS* is simulated by generation of pulses at the radar's pulse repetition frequency (PRF). Each pulse has a zero rise time and the same amount of RF energy (amplitude). The transmitted waveform is characterized in the model by constant time values for pulse width (PW) and pulse repetition interval (PRI). Figure 3.15-1 shows a typical pattern, or train, of pulses and the time measurements used to simulate them. The carrier frequency (*f*) and wavelength (λ) values are defined for electromagnetic propagation at the speed of light by the following relationship:

$$c = f\lambda$$

where: c is the speed of light

In addition, transmitter power or energy radiated by the antenna affects the amount of energy reflected by the target, which is evidenced in detection performance. Other waveform parameters affect tracking performance via synchronization with angle and range gates in the receiver.

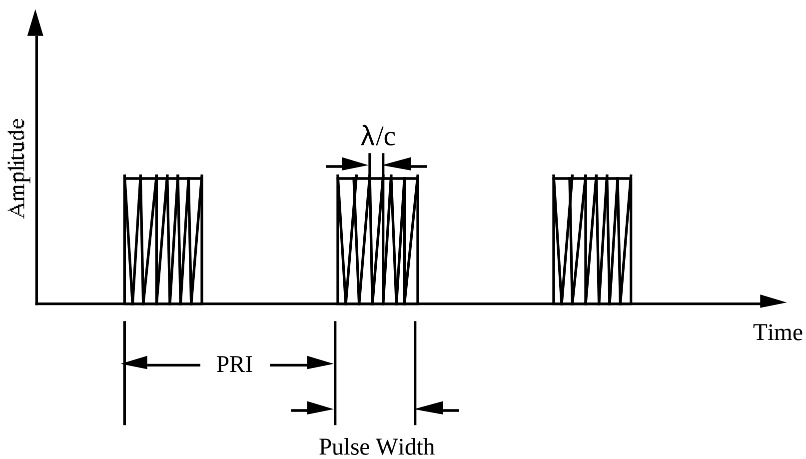

FIGURE 3.15-1. Typical *RADGUNS* Multiple Pulse Signal.

Data Source	Major Conditions	Statistical MOEs	Results
Range Test	Instrumented radar transmission	Mean t Test F Test Mann-Whitney U test	Tracking errors for *RADGUNS* range test waveforms not significantly different

3.15.1 Assessment - Case 1

Assessment Description

Test Data Description. Four characteristic parameters—transmitted power, pulse width (PW), pulse repetition interval (PRI), and wavelength—were used in the validation of this FE. Measured values from 11 different radar systems of the same type were extracted from test reports and compared to the parameters as represented in *RADGUNS*. Table 3.15-1 shows standard deviations of the range test sample populations and the corresponding values used in *RADGUNS* as percentages of the mean for the test sample. Only one of the waveform parameters, pulse width, is represented in the model by a value outside the standard deviation of the test sample population. This variation, however, had a negligible effect on tracking performance when identical model runs were compared.

TABLE 3.15-1. Waveform Generator Parameter Variances.

Parameter	Standard Deviation as % of Mean	*RADGUNS* Deviation as % of Mean	Sample Count*
Power	±14.72	+11.89	18
Pulse Width	±2.63	-3.75	16
PRI	±8.91	+0.22	17
Wavelength	±0.75	-0.25	12

* Parameters measured more than once on some radar systems.

Transmitted power affects the signal level returned from the target and thus the range at which the target can be detected. *RADGUNS* computes detection range R_{max} using the following form of the radar range equation:

$$R_{max} = \left[\frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 LN(S/N)_{min}} \right]^{\frac{1}{4}}$$

where:

Pt	=	Transmitted power
Gt	=	Transmitted antenna gain
Gr	=	Receive antenna gain
λ	=	Wavelength
σ	=	RCS
L	=	Total loss factor
N	=	Noise
$(S/N)_{min}$	=	Minimum Signal-to-Noise Ratio for detection

In the model, this equation is reduced to:

$$R_{max} = C(P_t \sigma)^{\frac{1}{4}}$$

where C represents a constant value for a given radar system frequency, gain, and noise level.

$$C = \left[\frac{G_t G_r \lambda^2}{(4\pi)^3 LN(S/N)_{min}} \right]^{\frac{1}{4}} = 530.78$$

This equation becomes, via substitution:

$$R_{max} = 530.78 \left[P_t \sigma \right]^{\frac{1}{4}}$$

For a constant RCS value of 1.0 m^2 and the baseline (version 1.8) modeled power,

$$R_{max1} = 9666 \text{ m}$$

If the transmitter power in the model is reduced to equal the range test measured mean (by 11.9%):

$$R_{max2} = 9365 \text{ m}$$

a 3.1% reduction in detection range results. The fact that the model uses a power value this much greater than the mean of the test sample means that detection ranges will be slightly optimistic for a given target RCS.

PW is a measure of the amount of energy in the signal, and the values used in *RADGUNS* represent best estimates of measurements for specific systems. Sensitivity analysis results suggest that significant variations in pulse width (±50%) would produce small changes in tracking error. Because the PW value used in the model is 3.75% above the mean value of the test samples, tracking errors for azimuth, elevation, and range would be increased by 0.225 mrad, 0.600 mrad, and 0.375 m, respectively. It is unlikely that these variations in error values could be further validated, given the capabilities of test range tracking equipment.

PRI is established for a radar system based upon requirements for unambiguous target range (R_u). PRI is the maximum time that the radar will wait for a return from a transmitted pulse, as calculated by:

$$\text{PRI} = \frac{2R_u}{c}$$

where: c is the speed of light

Fire-control radars operate at close ranges and use high pulse repetition frequencies (PRFs) that yield short PRIs due to the relationship:

$$\text{PRI} = \frac{1}{\text{PRF}}$$

As was the case with PW, PRI values used in the model were derived from measurements on specific systems. Sensitivity analysis results suggested that a I variation would not significantly impact tracking errors. This led to the conclusion that effects of the 0.22% higher PRI value on tracking performance would also be negligible.

Wavelength in *RADGUNS* is a constant value that is 0.25% less than the mean of the test samples. Wavelength affects detection range (see equation (1)), and sensitivity analysis results indicated that increasing wavelength by 0.25% would increase detection range by 0.13% (less than 13m) for a 1m^2 target. Close agreement between modeled and mean of measured values was comforting for a parameter with such a small standard deviation.

Validation Methodology. It has been suggested that model performance should reflect the average for a class, or family, of systems, so comparisons of tracking errors were made using the modeled (baseline) and means of measured waveform values. Three statistical methods were selected for the analysis of tracking errors over time. The parametric ***t*** and ***F*** distribution tests for means of small samples and the non-parametric Mann-Whitney U test, which was used as a statistical cross check because no assumptions as to distributions of the two sets of data were required. All three methods used 95% confidence intervals. Mean and RMS values were also used for comparisons of inbound and outbound segments.

Results

Model outputs using the baseline waveform and the measured mean waveform were generated using the input parameters listed in Table 3.15-2.

TABLE 3.15-2. Waveform Input Parameters.

Parameter	Value
Simulation type	SNGL
Track type	RADR
MTI	Off
Guns	Disabled
TPA	10.0 m^2
Flight path	Linear at 1000 m offset
Altitude	500 m
Velocity	200 m/s
Clutter	Disabled
Multipath	Not calculated
Average RCS	10.0 m^2

Figures 3.15-2, 3.15-3, and 3.15-4 illustrate azimuth, elevation, and range tracking errors, respectively, for the *RADGUNS* baseline and range test mean waveforms. Minimum range (the Y-axis crossover point) occurs at 100 s on each chart. The variations in frequency and magnitude of the azimuth and elevation errors are evident as the target range is decreased to within firing range and then increased again at target egress. Also of interest is the stronger correlation between range tracking errors for both waveforms.

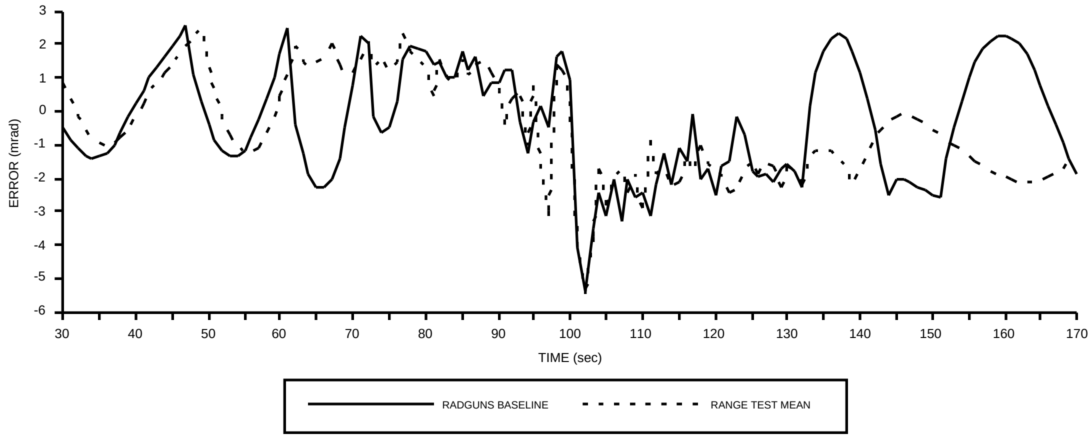

FIGURE 3.15-2. Azimuth Tracking Error Comparison.

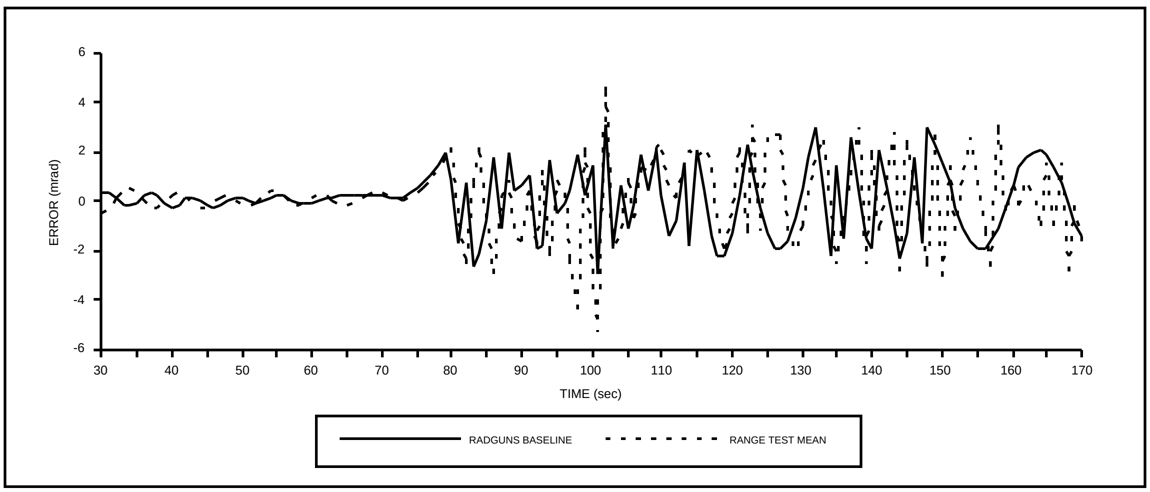

FIGURE 3.15-3. Elevation Tracking Error Comparison.

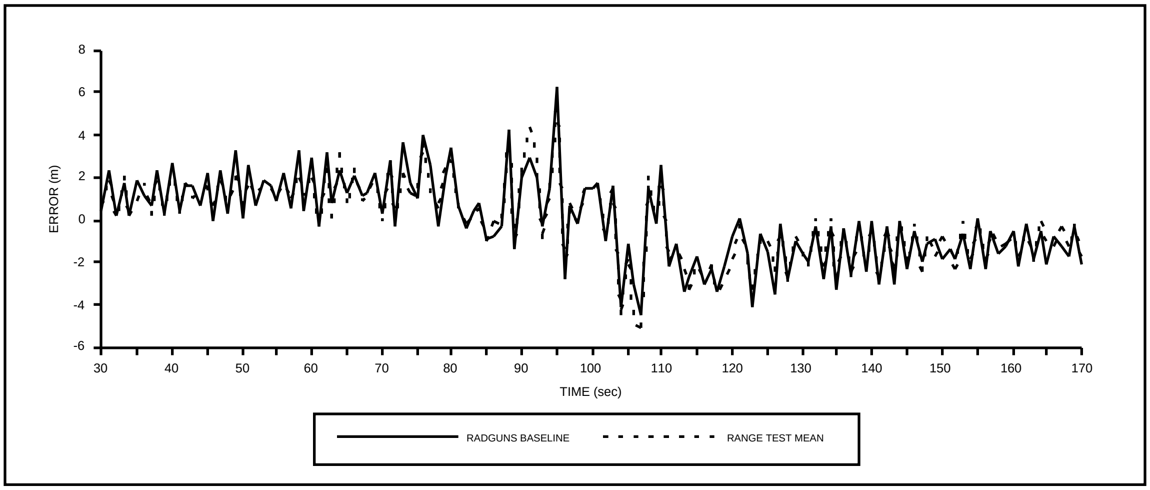

FIGURE 3.15-4. Range Tracking Error Comparison.

After parsing the modeled and measured mean waveform runs into inbound and outbound segments, mean and RMS tracking error values were computed. These are shown in Table 3.15-3 along with predictable detection ranges and three statistical test results for each pair of error distributions. If errors generated by the two waveforms are statistically different, then their mean values would come from different distributions. The Student's ***t*** and ***F*** test results for elevation and range errors were well within 95% confidence intervals; values outside these limits would force rejection of the null hypothesis (i.e., that the samples came from the same population).

TABLE 3.15-3. Total Waveform Variation Results.

Parameter	**RADGUNS Baseline Waveform**	**Range Test Mean Waveform**	**Student's *t* Distribution -1.995 < *t* < +1.995 ***	***F* Distribution For Means *F* < 3.910 ***	**Mann-Whitney *U* Test -1.96 < z_u < +1.96 ***
Detection Range (m)	16,358	15,840			
Mean Inbound Azimuth Error (mr)	0.271	0.636	***t*** = -3.453	***F*** = 3.689	z_u = 1.813
Mean Outbound Azimuth Error (mr)	–0.909	–1.676	***t*** = 3.416	***F*** = 10.164	z_u = -1.484
RMS Azimuth Error (mr)	1.705	1.519			
Mean Inbound Elevation Error (mr)	0.123	–0.074	***t*** = 0.804	***F*** = 0.789	z_u = -0.542

TABLE 3.15-3. Total Waveform Variation Results. (Contd.)

Parameter	RADGUNS Baseline Waveform	Range Test Mean Waveform	Student's t Distribution $-1.995 < t < +1.995$ *	F Distribution For Means $F < 3.910$ *	Mann-Whitney U Test $-1.96 < z_u < +1.96$ *
Mean Outbound Elevation Error (mr)	-0.025	0.285	t = -1.083	F = 0.950	z_u = 1.217
RMS Elevation Error (mr)	1.247	1.530			
Mean Inbound Range Error (m)	1.331	1.255	t = 1.200	F = 0.104	z_u = -0.313
Mean Outbound Range Error (m)	-1392	-1316	t = -0.880	F = 0.049	z_u = 0.375
RMS Range Error (m)	1.814	1.719			

* Critical values at the 0.05 significance level, or 95% confidence interval. Student's ***t*** and Mann-Whitney ***U*** tests are two-tailed.

Azimuth error comparisons, however, yielded both ***t*** and ***F*** test values outside the confidence interval. Only the ***F*** test for the inbound segment produced a result that was barely below the critical value. These disparities are due to differences in frequency content of the error plots at long ranges from the threat radar. If these data portions (beyond 6-7 km) had been excluded, results for azimuth would have been similar to those for elevation and range. The Mann-Whitney U test indicates that the hypothesis that the means are from the same distributions for all six cases cannot be rejected, but values for elevation and range were still much better than for azimuth.

Conclusions

This assessment of the transmitted radar waveform as modeled in *RADGUNS* reinforced previously established sensitivities to power, pulse width, *PRI*, and wavelength parameter changes. Variations in detection range and tracking errors for waveforms based upon test data samples were as expected and very small in magnitude. Statistical tests supported the conclusion that tracking error distributions produced by *RADGUNS* and the range test mean waveforms for the same engagement conditions were not significantly different. Nevertheless, in an effort to improve model fidelity, the user group/CCB may decide to update modeled waveform parameters with empirically derived ones. Therefore, a Model Deficiency Report was submitted to allow for consideration of these minor changes.

This validation effort quantified the influence of minor transmitter variations on tracking performance for this type of radar system. The minor effects of waveform differences on tracking performance were encouraging in assigning confidence to the simulation of a particular transmitter by the model, but few complex algorithms are used to accomplish this function. Waveform parameters are represented in the model by constants that are used to compute other variables needed for calculation of RF energy returned, but the significance of any parametric variations is produced via simulations of the radar antenna, receiver, and tracking servo functions.